Trends in Cognitive Sciences

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Opinion

The Integrative Self: How Self-Reference Integrates Perception and Memory

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We propose a new account of how self-reference affects information processing. We report evidence that self-reference affects the binding of memory to source, the integration of parts into perceptual wholes, and the ability to switch from a prior association to new associations. Self-reference also influences the integration of different stages of processing, linking attention to decision making, and affects the coupling between brain regions mediating self-representation and attention to the environment. Taken together, the data suggest that self-reference acts as a form of 'integrative glue' which can either enhance or disrupt performance, depending on the task context. We discuss the implications for understanding the self, and future directions for research.

Trends

Relating a stimulus to the self (self-reference) enhances perception and memory.

After relating a stimulus to the self, associating the stimulus to another person is difficult.

Self-reference leads to coupling across different stages of processing.

Self-reference leads to increased functional coupling between brain regions.

Effects of self-reference are proposed to reflect increased binding between stimuli, between different stages of processing, and between brain areas.

The Integrative Self

What does having a self-representation do for us? Freud (1949) famously distinguished between the id, the ego, and the super-ego, arguing that self-representation through the ego mediates between basic instinctive drives (the id) and societal demands (the super-ego) [1]. The self acts to maintain a homeostasis between our drives and our social context. Other theoreticians, however, have argued that the self does not do anything for us because there is no single, integrated self-representation. For example, William James (1890) distinguished between a physical, a mental, and a spiritual self, each of which had its own attributes [2]. Others argue that the self is a convenient fiction, somewhat similar to the concept of a center of gravity, in that it serves as an explanatory narrative without serving as a processing mechanism that generates such a narrative [3,4]. We argue here that the presence of a self-representation does indeed do something for us – notably it acts as an integrative hub for information processing, helping to bind together different types of information and even different stages of processing. Our argument for 'the integrative self' is based on five pieces of evidence, each of which occurs when people make reference to the self within the task they are performing. We show that self-reference (i) helps to bind memories to their source, (ii) increases perceptual integration, (iii) makes it difficult to re-bind a new association to a stimulus formerly linked to the self, (iv) modulates the coupling between attention and decision-making, and (v) increases interactions between brain regions. Self-reference provides a form of associative 'glue' for perception, memory, and decision making and, through this, acts as a central mechanism in information processing. A framework for these ideas is presented in Figure 1.

Self-Reference and Binding in Memory

There is now a great deal of evidence indicating that memory is enhanced when people categorize stimuli in relation to themselves rather than others [5–13]. For example, a recent study [14] asked participants to make judgments about either the self-relevance of positive and negative adjectives, or about the semantic meaning of the items. There was better recollection

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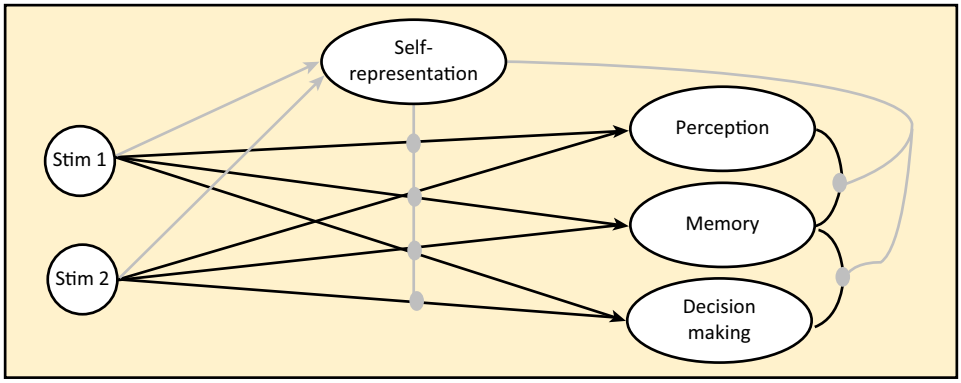

Figure 1. A Framework for Self-Related Integrative Processing. In this framework we propose that the activation of self-representations modulates (grey nodes) the mapping between stimuli (Stim) and perception, memory, and decision making, and also between different stages of information processing (perception, memory, and decision making).

Glossary

Independent race model: a formal model of performance if there is independent processing of two targets. This model is violated if performance with redundant targets is even more efficient than can be predicted from the model.

Left posterior superior temporal sulcus (LpSTS): the posterior portion of the superior temporal sulcus in the left hemisphere, which we link to stimulus-driven attention to a stimulus

N2 and P3: electroencephalography (EEG) components evoked about 200 ms and 400–500 ms after the presentation of a stimulus, typically thought to reflect attentional engagement and decision making respectively.

Redundancy gain: the gain in performance when participants are presented with two exemplars of a target compared with when they receive a single target item.

Self-reference effect: the better performance on stimuli that are related to the self compared with stimuli related to other people.

Ventromedial prefrontal cortex (vmPFC): a brain region strongly associated with self-related processing.

for items judged in relation to the self compared to items whose meaning was evaluated. Furthermore, participants recalled more episodic details about items judged in relation to themselves compared to items judged for meaning. This held for both older participants and participants in their late teens and twenties. This result, not only for better general recall but also for the integration of perceptual detail in the memory, fits with the idea that **Self-reference effects** (see Glossary) enhance the binding together of different forms of information (here the perceptual detail along with any verbal memory). In another study [15], researchers showed children images of their own or another child's face together with an object, with the task being to judge whether the child liked the object. When subsequently tested for memory, the children not only demonstrated better performance on objects judged in relation to themselves but they also performed better when asked to remember which face the remembered object was presented with [15,16] (Figure 2A). There was better binding in memory of all the information initially present – thus people were not only better able to remember which items occurred but also whether they had judged the item in relation to themselves or other people. These studies indicate that the result holds across a wide age-range (from children to older adults). Indeed, these effects of self-reference on memory can even increase in older adults [17–19], perhaps because older people become more self-focused, because they have problems in seeing other people's perspective [20,21], or because of reduced memory and executive processes outside those based on self-reference [22–26]. This last argument raises the possibility that effects of self-reference operate independently of executive and elaborative encoding strategies that otherwise modulate memory.

The above findings (notably [14]) indicate that self-referential effects cannot be reduced merely to effects of deeper semantic encoding. Other work indicates that self-reference improves memory even when the effects of deep semantic coding are absent. For example, a neuropsychological study [27] examined a patient, GA, with both a semantic impairment [28] and severe amnesia. GA was shown objects which were assigned either to him or the experimenter. In a second condition he made a judgment either about whether an object was living or non-living (deep semantic classification), or about its physical size (surface classification). GA had enhanced recognition and source memory for objects classified as belonging to him compared to objects assigned to the experimenter. These effects did not differ in magnitude from those found with age-matched controls. However, there was no effect of semantic classification versus surface classification, whereas controls showed clear benefits after semantic classification (Figure 2B).

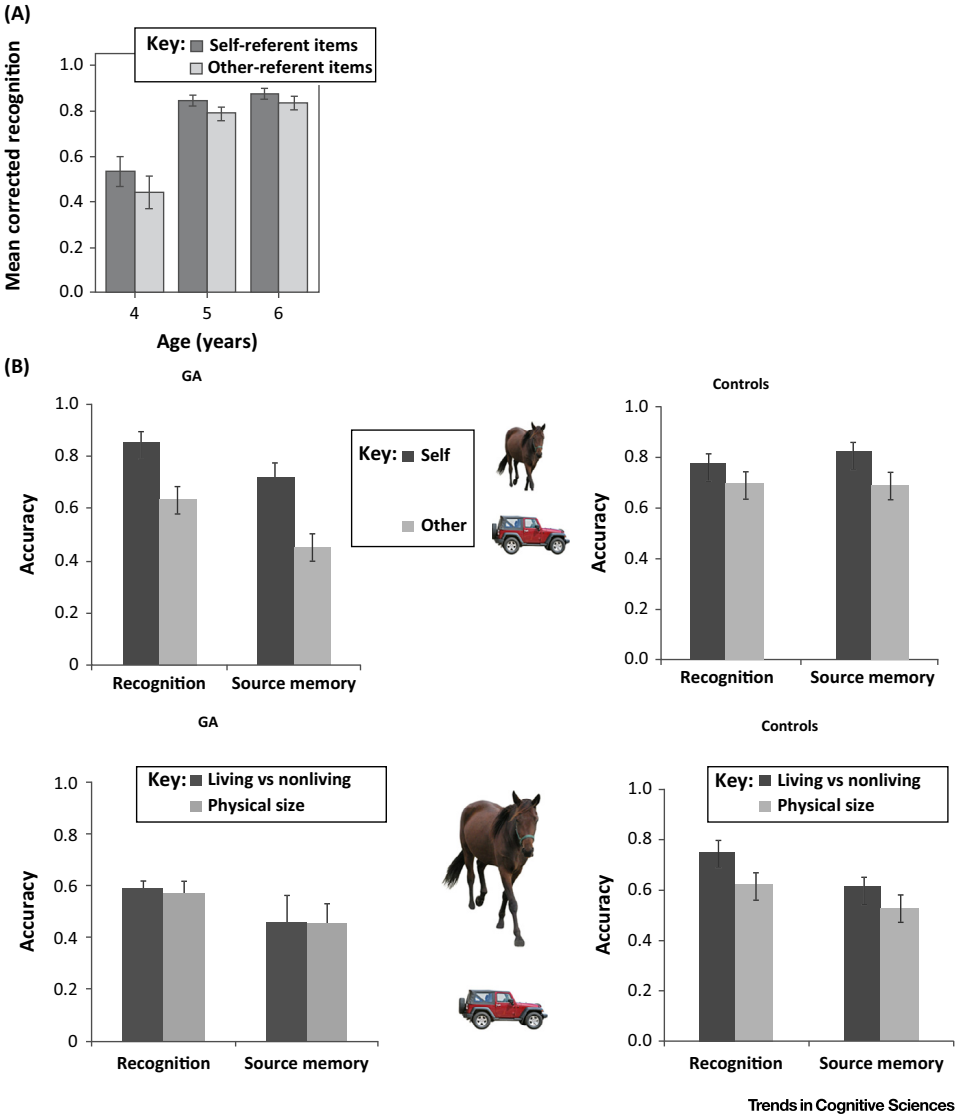

Figure 2. The Self-Reference Effect in Memory. (A) Corrected proportional recognition scores of children 4, 5, and 6 years old show better recognition performance for items referenced against the self relative to other people across the three groups. Reprinted from [15] with permission from John Wiley and Sons (©2013). (B) Results from patient GA (category-specific impairment and amnesia) and age-matched controls on recognition and source memory tasks following judgments about ownership by the self or another person (left), or judgments about whether stimuli were living or non-living (a semantic classification task) or whether the images were large or small (a surface classification task). The control participants showed improved recognition and source memory following both self-reference and semantic classification (compared to when reference was made to another person and to when judgments were made about physical size). By contrast, GA had enhanced memory after self-reference but showed no reliable effects of semantic versus surface classification. The data indicate that effects of self-reference can occur independently of the effects of semantic elaboration on memory. This affects the binding of memories to their source (in the source memory task) [27].

These data indicate that the effects of self-reference are not only stronger than the effects of semantic classification [29] but also that they are independent of semantic encoding effects.

Self-Reference and Binding in Perception

There is evidence that self-reference also enhances the binding of visual features in perception. Studies of face-processing show faster classification of self faces than the faces of other people

when participants classify faces as self, friend, or stranger [30,31]. This holds when faces are inverted (when face features may play a strong role in classification) and when the faces are upright (when configural information is more salient). Interestingly, there is an advantage for friend over stranger faces too, but only when the faces are upright [30]. This suggests that friend-faces benefit from the configural properties present in upright faces, while self faces have both enhanced integration of features into configurations and feature processing, and thus gain both when upright and inverted.

This qualitative difference between the processing of self and friend faces indicates that enhanced self-face processing may not be reduced to greater effects of familiarity for self relative to other stimuli. This argument is also supported by work using neutral shapes, which also indicates that self-reference improves perceptual integration. Work on neutral shapes has used a simple associative-matching procedure [32,33]. Participants associate a personal label (e.g., stranger, friend, you) to a shape (triangle, circle, square) [33]. Next, they judge if a shape–label pair matches (triangle–stranger, square–you) or mismatches (triangle–you, square–stranger). Match times are substantially faster for stimuli associated with the self (square–you) than for stimuli associated to other people (triangle–friend, circle–friend), even though the shapes are equally familiar. In addition, the contrast of the stimuli was reduced in some experiments. Reducing the contrast has a greater effect on stimuli associated with a friend than stimuli associated with the self [33]. This is consistent with perception being enhanced for self-related stimuli, such that they suffer less when their contrast is reduced.

This procedure has subsequently been used to assess more specifically whether self-reference affects perceptual integration between stimuli. After forming associations between one personal label and two shapes (you–circle, you–square) [34], participants were asked to identify single or pairs of shapes as referring to the self or a friend. When the shapes referred to the self, there was a large benefit from presenting two relative to one exemplar – this is known in the literature as a **redundancy gain** [35–37]. Formal mathematical modeling showed that this enhanced redundancy gain was greater than could be expected if there were independent processing of each of the self–shape exemplars (Figure 3). The same benefit was not apparent for stimuli associated with a friend. Previous results indicate that redundancy gains are particularly large if the stimuli are parts of a grouped configuration [38] or object [39]. These results fit with a proposal that self-related shapes are integrated into a single representation so that participants respond to an integrated 'self Gestalt'.

Switching from the Self

If self-reference increases binding between stimuli then, in addition to enhanced initial learning of self-associations, we may make a second prediction – namely that it may be difficult to form new associations to stimuli formerly linked to the self. This has been shown in a study of switching costs [40]. Following previous studies [32–34], participants first carried out a block of perceptual matching trials with shapes assigned to personal labels (square–you, triangle–friend, circle–stranger) and then formed new shape–label associations (e.g., square–friend, triangle–stranger, circle–you). The results showed faster matches to self-associated stimuli when the second association was formed (circle–you < square–friend and triangle–stranger), consistent with the self enhancing binding. However this came at a cost for new associations to a shape that was formerly linked to the self (square–friend and square–stranger > triangle–stranger and circle–friend) in errors and reaction times. Furthermore, individuals who showed a strong self-advantage when matching shapes based on the initial associations had a greater cost when the self-shape was reassigned to a new association. This correlation was weaker for friend-associated stimuli [40]. The data indicate that enhanced binding between the self and a shape made it difficult to later reassociate that shape to another personal reference. There is a 'sticky trace' from self-binding.

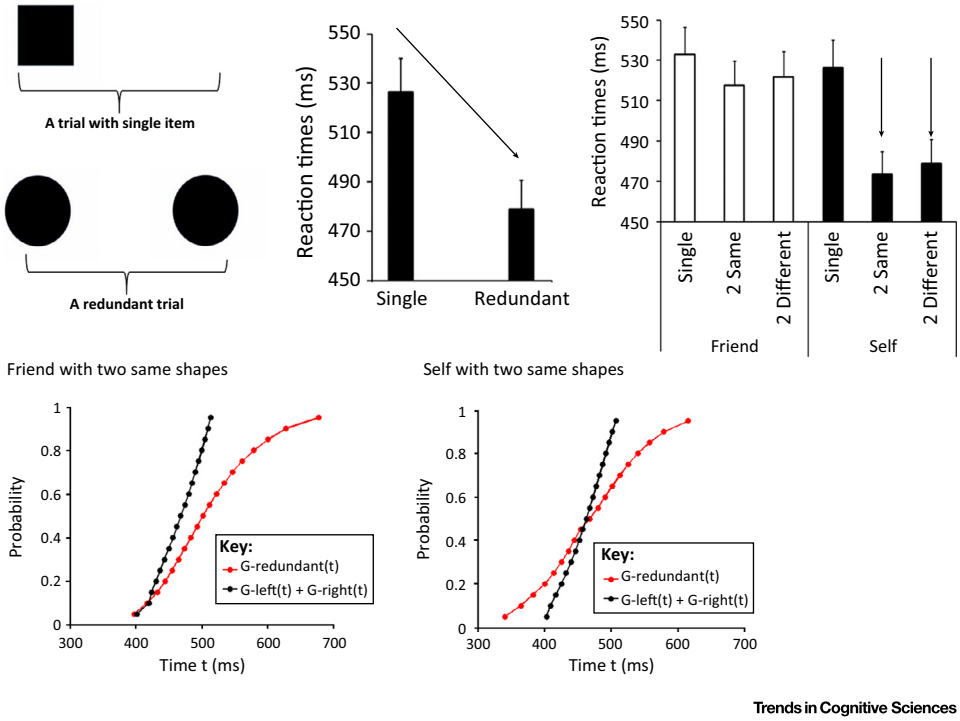

Figure 3. Mathematical Modeling of Redundancy Gains. (Top) When participants are required to identify whether a square or a circle is present, reaction times are faster on redundant (two item) than single-item trials [34]. (Bottom) Formal tests of redundancy gains for self- (right) and friend-associated (left) stimuli by assessing if there is violation of independent processing of the redundant stimuli. The graphs show the cumulative probability of a response being made as a function of reaction time (the probability of responding increases as reaction times become slower). We show the results for redundant self-stimuli and the results predicted by adding together the probability of responding when single stimuli are shown. This is the maximum performance (the boundary performance) that can be predicted if there is independent processing of the elements in a redundant stimulus. Note that the graph for redundant self-stimuli falls to the left of the boundary for processing the elements independently. This provides strong evidence for the self stimuli being integrated such that participants respond to a representation in which the elements are integrated into a whole, rather than being coded independently of each other. Copyright ©2015 American Psychological Association. Adapted from [34]. The use of APA information does not imply endorsement by APA.

Self-Reference Binds Stages of Processing

We have presented evidence that self-reference affects binding between stimuli in memory and in perception, and that it leaves a 'trace' that can disrupt the binding of new information with a self-related stimulus. Alongside evidence on stimulus binding, there are data indicating that self-reference helps to integrate different stages of processing. Consider the findings reported in a study using event-related potentials (ERPs) [41] to examine the effects of facial cues on the orienting of visual attention. On each trial there was a central face which turned either to the left or right. This was followed by a visual target, randomly left or right of center, to which participants made a discrimination response. Turning the head towards the target facilitated responses, especially when the face was that of the participant. This benefit from turning the head to the target modulated two components of the event-related potentials recorded using electroencephalography (EEG). There was both an enhanced **N1** component to self-related faces and a reduced **P3** component. An enhanced N1 component has been linked to greater attentional responding to a stimulus [42,43], while reductions in the P3 component are associated with greater certainty in decision making [44]. Notably there was a correlation between the self-bias effects for the two components – individuals who had a larger effect of the self on attention (the N1 effect) also had a stronger effect of the self on decision making (P3). This suggests that

heightened attention to the self (indexed by the N1 effect) is coupled to an increase in certainty in decision making (indexed by the P3 effect). Consistent with the argument for increased effects of cueing owing to increased attention to the self cue (the turning face), other studies have shown that images of the self as a central distractor disproportionately hurt performance on overlaid targets, suggesting that self-faces attract more attentional resources, thus reducing performance on other targets [45]. This increased attention may then enhance binding between different stages of processing.

Self-Reference Enhances the Coupling Between Brain Regions

There is also neural evidence indicating self-reference affects the coupling between different stages of processing – in this case, the retrieval of a self-representation and the allocation of attention to the environment. fMRI studies have measured brain activity while participants carried out the associative matching task with shapes linked to personally relevant labels [46]. Two areas have been shown to be reliably more active when self-related stimuli are presented compared with when participants see stimuli associated with other people: the **ventromedial prefrontal cortex** (vmPFC) and the **left posterior superior temporal sulcus** (LpSTS) (Figure 4). Across many studies the vmPFC has been implicated in self-representation and is activated when participants refer stimuli to themselves relative to other people [47–59]. The LpSTS can be considered part of a ventral attention system concerned with orienting attention to the environment [60]. Mathematical modeling of the fMRI data, using dynamic causal modeling [61], revealed a best-fitting model in which the vmPFC and LpSTS had excitatory connections, and the presence of self-related stimuli increased the functional connectivity between the vmPFC and the LpSTS. The strength of these connections also predicted behavioral responses to self-related stimuli (Figure 4). From this evidence we conclude that self-reference enhances the neural coupling between regions concerned with a core self-representation (vmPFC) and with distinct domain-specific regions associated with different components of the self, including self-related attention (LpSTS).

Indeed, a meta-analysis has demonstrated that there is enhanced neural coupling for self-processing (vs other-related processing) between the vmPFC/pregenual anterior cingulate (pACC) and several other regions including the bilateral anterior insula, left striatum, right thalamus, and amygdala [62]. These results match the resting-state functional connectivity when the pACC is treated as a seed [62]. Similarly, clinical work has shown changes of neural coupling between the medial PFC and other brain regions when patients process self-related information [63,64]. For example, researchers reported that altered self-awareness in Alzheimer's disease patients is associated with changes in functional connectivity between the medial PFC and other cortical midline structures and dorsolateral prefrontal cortex [63]. This last result indicates that the changes in functional brain connectivity related to the self may play a causal role in self-awareness.

Is the Self Special?

Our arguments have stressed the role of self-reference in binding. There is a major question of whether self-reference is special in this respect or whether the effects stem from another underlying factor such as the familiarity of the stimulus, its inherent reward value [65], or its emotional valence [66]. Although we do think that a definitive answer cannot be given currently, there is suggestive evidence that the effects of self-reference may not be completely reduced to these factors. For example, self-reference effects have frequently been contrasted against effects of reference to a close other, including the participant's mother [33], and the effects of self-reference are typically dominant. In addition, in procedures such as associative learning with neutral shapes, familiarity effects can be eliminated when participants respond only to the shapes, but self-bias effects remain [34,67]. Biases are also not found when associations are made to neutral objects varying in familiarity [68].

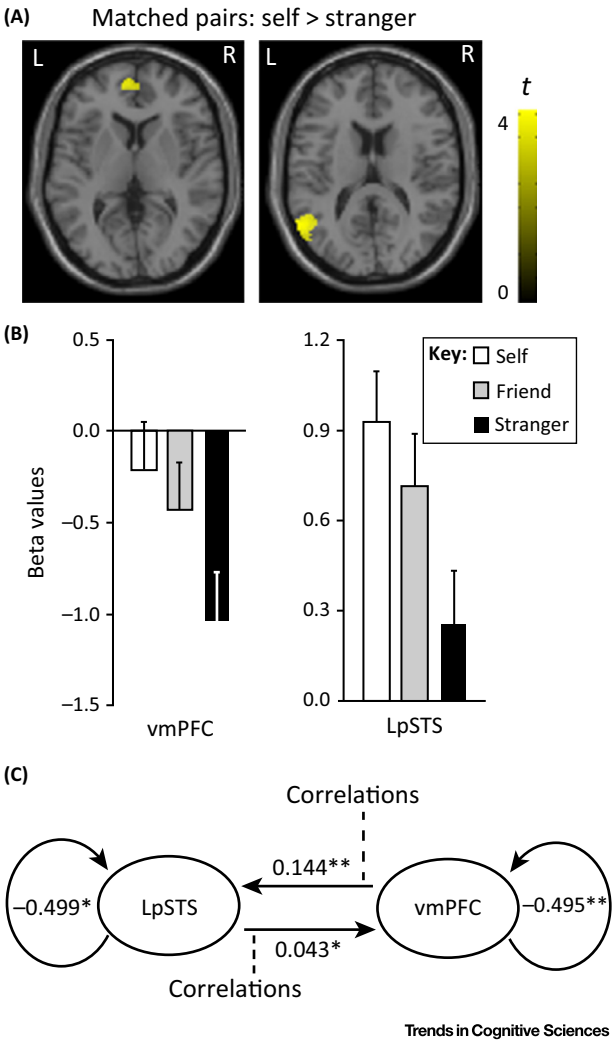

Figure 4. Self-Reference Enhances the Coupling of Activity Across Brain Regions. (A) Brain regions where activity for self-related stimuli is greater than activity for stimuli related to other people. Ventromedial prefrontal cortex (vmPFC) is shown on the upper right and left posterior superior temporal sulcus (LpSTS) is shown on the upper left. (B) Blood oxygen level dependent (BOLD) activation to self, friend and stranger stimuli in vmPFC and LpSTS. (C) The best-fitting model showing excitatory functional connectivity between the LpSTS and the vmPFC. * $P < 0.05$; ** $P < 0.01$. The strength of the connection from vmPFC to LpSTS correlated with reaction times to self-related stimuli [46].

In addition, studies of perceptual integration have examined associations to reward as well as to the self [34]. The striking redundancy gains to self-related stimuli (Figure 2) are reduced for reward-related items, suggesting that reward has weaker effects on perceptual integration. By contrast, the relations between the self and reward may depend on the individual. Researchers pitted the effects of reward against the self by giving a higher reward value to stimuli associated with other people compared with stimuli associated with the self [69]. Participants with a strong self-bias were minimally influenced by the differential reward values, but participants with weak self-bias were affected. It may be that there are individual differences in how much the heightened effects of self-reference are dependent on associated underlying factors such as reward, with this being the case in some individuals but not in others with a strong, autonomous self-representation.

Theoretical Implications

If our argument about self-reference affecting binding is correct, then several theoretical implications follow. One relates to the longstanding controversy on whether there is a common self-representation or a number of distinct self-representations [1,2]. Our suggestion is that there are pervasive effects on binding within and across different levels of processing. This enhanced

binding will allow information related to the self to be rapidly assimilated and accumulated, enabling a core self-representation to be formed. This core self-representation should be accessed across different tasks and levels of processing, even if there are other distinct aspects of the self tapped by different tasks (e.g., a body-based representation which may be represented in different neural areas to a more conceptual representation of the self). Consistent with this, a recent meta-analysis of brain imaging data has indicated a set of common brain regions that are sensitive to the self/other distinction across tasks as divergent as face recognition and trait judgments (including cortical midline structures and the insula [48–51]), while other brain regions show task-specific responses that are enhanced to the self (e.g., in occipital regions in face-recognition tasks). The cortical midline structures have also been shown to be more strongly activated by self-related stimuli than by stimuli related to other people in tasks ranging from visual self-recognition [54–57], autobiographical memory [10,58], and self-evaluation [59]. We suggest that this reflects the activation of a core self-representation. Whether binding processes vary for the core self-representation and for any of the more distinct aspects of the self is unknown, although we discuss issues related to the mechanisms of binding below.

A second implication relates to the philosophical argument about whether the self serves as a processing mechanism or whether it merely stems from a narrative that reflects, but does not modulate, ongoing processes ([3,4], but see [70,71]). The evidence we have summarized here indicates that self-reference alters ongoing processes by enhancing binding. This in turn suggests that self-reference operates as a mechanism that changes ongoing processing, and is not merely a narrative-based reflection on the processing that may have taken place.

A third implication relates to the idea of 'self-expansion' in social psychology. Researchers have put forward this idea to explain the tendency for people to expand the representation of themselves, such that the in-groups that they are members of become incorporated into the self [68]. Some researchers [72,73] argue that there is a basic motivation to expand the self so that more attributes are available to help an individual attain a goal. The binding effects we have summarized can provide a mechanism for self-expansion because stimuli (and perhaps more abstract concepts such as our 'in-group') can be linked more rapidly to the self than to other people. There is an asymmetric expansion of our self-representation compared to the representations of others, fitting the self-expansion model.

Individual Differences, Psychopathology, and Fast Access to the Self

There remain many questions. One concerns the neural mechanisms that underlie the increased binding brought about through self-reference, which are currently unclear. There are also individual differences in the magnitude of self-bias effects which are stable within participants [74]. The factors that lead to such differences are not understood, nor is it clear whether differences found within the normal population can be linked to differences in self-representation and binding in psychological disorders such as schizophrenia and depression. The approach we are advocating, however, does allow bridges to be built between the underlying neural substrates, individual differences, and psychopathology. For example, one possibility is that contrasting levels of global, excitatory neurotransmitters (e.g., glutamate [75]) are recruited through self-reference, and that this leads to the ubiquitous increases in binding; this idea is captured in the Outstanding Questions. It would then follow that individual differences in the normal population and in cases of psychological disorder might reflect contrasting strengths of binding, moderated by variations in neurotransmitters (see Outstanding Questions).

Within the framework in Figure 1, there would need to be rapid access to self-representations to generate an effect on ongoing processes. There is some supportive evidence for this. Notably, self-reference effects are associated with activation of the anterior **N2** EEG component over central frontal regions [76]. We propose that rapid activation of self-representations in these brain

regions then feeds back to modulate processing in perception, memory, and decision making. Analogous arguments to this have been made in relation to object recognition, suggesting that rapid access to object representations in orbitofrontal cortex helps to 'tune' visual processing to initial perceptual 'hypotheses' [77]. We suggest that there is a similar rapid process of tuning to self-representations.

Concluding Remarks

We conclude that self-reference enhances the binding of information in perception and memory, and that this can help to explain the pervasive influence of self-reference on information processing. Learning more about the neural basis of these effects will be crucial for further understanding of what the self does for us.

Acknowledgments

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Outstanding Questions

Are the processes that bind stimuli in perception the same as those that bind stimuli in memory? Is there a single form of binding induced by self-reference?

How is integration achieved across different stages of binding? Are the mechanisms involved in self-related binding across different stages of processing the same as those involved in binding within a processing stage?

What are the neural mechanisms of self-related binding – are particular neurotransmitter systems involved?

What are the exact relations between self-related biases and basic motivational drivers such as reward and emotion?

Is there fast access to self-representation, which modulates further processing?

Are there distinct aspects of the self (an embodied self, a conceptual self), only some of which generate greater integration in information processing?

What characterizes individual differences in self-related bias? Can such differences be understood in terms of variations in integrative processing, and are there differences linked to disorders such as schizophrenia and depression?

To what extent are negative effects of the self on switch costs similar to other cognitive 'carry-over' effects such as negative priming and inhibition of return?

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